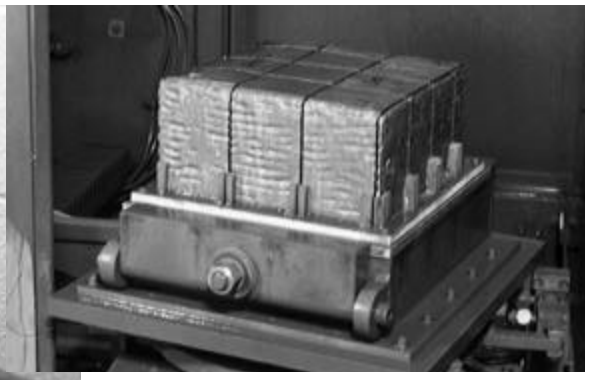
John Wohlgemuth, Solarex/PIX04568



John Wohlgemuth, Solarex/PIX04571

By casting larger ingots of silicon, Solarex can double production capacity for 1/5 the cost of installing new casting stations. In one option shown here, the larger ingots are sawed into nine bricks (upper right) that are then processed into thin silicon wafers measuring 14 cm on a side.

of cast polycrystalline silicon. Solarex assessed each production step: casting the material, sawing ingots, processing cells, laminating, and finishing. Improvements incorporated into the processing of cells should reduce costs and increase the minimum average cell efficiency to 15%. For example, Solarex has modified its casting stations to produce larger ingots. From these ingots larger bricks can be cut, yielding larger cells for modules. By FY 1997, Solarex's entire plant will be processing these larger ingots with the newer processing steps. Another improvement—replacing blade saws with wire saws— has reduced production costs by 10 cents per wafer. With other improvements, including identifying and qualifying a new low-cost backsheet material, an improved mounting system for frameless modules, and an improved electrical termination process, Solarex expects to produce modules for about $1.20 per watt at a 15-megawatt-per-year production facility.

Phase 4A2 of PVMaT, which began in FY 1995, produced promising results in FY 1996.

ASE Americas, Inc. (formerly Mobil Solar), Billerica, MA, manufactures photovoltaic wafers, cells, and modules using an edge-defined, film-fed growth process developed at Mobil Solar. ASE's goal is to reduce wafer, cell, and module manufacturing costs by 25%, relative to pre-PVMaT Phase 4A2 levels. In this effort, ASE is using a PVMaT-developed lower-cost, environmentally safe process to remove their diffusion glass from wafers. They have also improved the process for integrated interconnects, lamination, and cell fabrication. With these changes and improvements in solar cell fabrication technology, ASE expects to produce cost-effective cells with an average efficiency of 15.5%.

AstroPower, Inc., Newark, DE, is reducing the manufacturing cost of its commercial Silicon-Film™ cells and modules. Their approach is to make the AstroPower Silicon-Film™ material in wider sheets that make better use of the material, require less labor per area of modules produced, and allow greater variety of products for different markets. The company's current commercial product is 15.5 cm wide, with sheets from prototype production measuring 30 cm wide. AstroPower expects to increase their production capacity of Silicon-Film™ sheets to 20 megawatts per year in the future.

Iowa Thin Films Technologies, Inc. (ITF), Ames, IA, is increasing their throughput of amorphous silicon deposition on continuous polymer substrates, and the subsequent metalization, laser-scribing, and welding processes to reduce costs. In FY 1996, ITF increased throughput in the printer and scriber from 2 inches per minute to 14 inches per minute by changing the control strategy for aligning the material in the printer. Work on their submodule lamination process has increased throughput from 20 ft^2 per hour to 240 ft^2 per hour. Other areas of improvement included developing new water-soluble insulating ink printing and roll-based laminating processes, identifying alternative methods for welding shunts in cell-interconnects, and automating busbar attachment and web cutting. These improvements have reduced manufacturing costs by 68%.

Siemens Solar Industries, Camarillo, CA, is reducing the cost and improving the reliability of their commercial, Czochralski, crystalline-silicon modules. They are testing prototype modules made from larger, 225-cm^2 cells, which can reduce module costs per watt by 18% and increase manufacturing process yields by 15%. Breakage can reduce yields by 20% to 40%, so Siemens is also investigating lowering costs through reduced breakage while continuing to thin the cells. In addition, a new prototype junction box combines low cost with improved design.

Photovoltaics International (formerly Solar Engineering Applications (SEA) Corporation), Sunnyvale, CA, is reducing manufacturing costs for its linear concentrating PV modules by expanding the continuous processing of key

components. The lenses and side panels of the modules are being extruded, and design is under way for a 50-megawatt-per-year production facility for these components. In addition, the company is developing an automated receiver assembly process, new roll-forming technology for fabricating panel frames, and is investigating a new way to bond plastic collector components without using solvents. Photovoltaics International's long-term goal is to produce 50 megawatts per year of concentrator modules at a cost of $2.00 per peak watt.

Industrial Expansion

More than 55 megawatts of new PV manufacturing capacity are now in various stages of development—almost 60% of the current worldwide annual sales. Siemens Solar Industries is expanding its operations, with new investments in facilities in Vancouver, WA, and Camarillo, CA. United Solar Systems Corporation is starting up a manufacturing plant in Troy, MI, to produce the new PV roof shingle. Solarex, a business unit of Amoco/Enron, is building a new plant in Toano, VA, that will employ up to 100 people.

Of the 55 megawatts of PV production capacity under development, almost 29 megawatts of new thin-film manufacturing capacity are now on line or are planned for completion by 1998.

Module and Array Development

Assessing the performance of modules and arrays is an important part of the DOE PV technology development program. Researchers are developing new ways to predict system performance in the field. In addition, ongoing work with manufacturers assesses the wear and tear on modules and how manufacturing processes can be changed to increase durability.

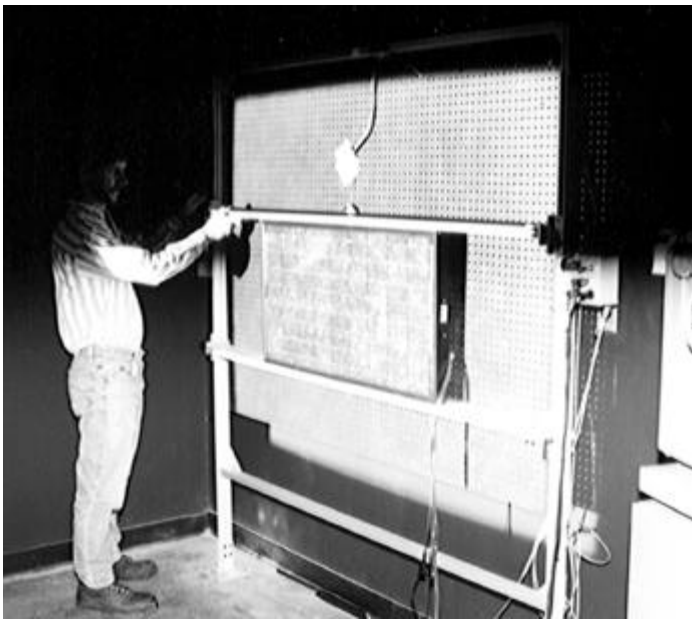
Manufacturers now offer 20-year warranties on crystalline-silicon modules and up to 10-year warranties on thin-film modules. To provide even longer warranties, they want to understand the complex changes that can occur in their product after years of exposure to sun, wind, dust, moisture, and daily temperature cycles.

The DOE PV program developed and is transferring to industry a method to extract information about PV modules by taking core samples. Taking tiny core samples with a vertical mill and coring tools, researchers at Sandia and the Florida Solar Energy Center analyzed more than 500 samples from 10 different modules. The 5/16-inch-diameter samples are analyzed using all the laboratory tools available, to find undesirable compounds at material interfaces or degraded solder bonds that lower performance. Such detailed analysis could not be performed on whole modules. Depending on what is found at material interfaces, the source of contamination is sought. These findings have already led to changes in manufacturing techniques.

In addition to gaining valuable information about the internal chemistry of modules after years in the field, the researchers have perfected the sampling technique and are preparing detailed instructions on how to use it. Several companies have already set up the tools required and will use them to sample for quality control during production (for example, encapsulant adhesion) and for post-mortem analysis of modules from the field.

This core sampling technique was developed during work with individual PV manufacturers to solve problems unique to their products. By making the laboratories of the DOE PV program

Steve Rummel, NREL/PIX04569



Steve Rummel, NREL/PIX04570

The DOE laboratories test industry's modules outdoors (left) under natural sunlight and indoors (right) using solar simulators. This new solar simulator can accomodate the largest new modules by illuminating a 5-ft by 7-ft area with an irradiance level matching ASTM standards.

available to industry with the assurance of confidentiality, researchers identified the sources of contaminants and other mechanical problems. Companies then went on to modify their manufacturing processes.

Another approach to increase reliability is to develop monitoring systems and to use models that predict expected performance in the field. In the past, some utilities have hesitated to offer PV services in lieu of extending utility lines to customers, even when PV could save money. They hesitated because they could not continuously evaluate how the system was performing. The DOE program, through Sandia, is working with Southern California Edison and Arizona Public Service to provide on-line monitoring of remote PV systems 24 hours a day. With this kind of monitoring, the utility can anticipate a problem developing and maintain the reliability of utility systems that customers expect.

For customers, predictability of system performance reduces uncertainty and risk. To help decrease uncertainty, Sandia researchers have developed and validated a model to predict the performance of a PV array for all operating conditions. The model uses inputs for time of day, measured temperature, and measured irradiance—along with data on the PV array design—to predict output. The model was validated using four systems ranging from 1.5 to 340 kilowatts.

Knowing expected output is important to system designers, buyers, and operators. Predicted output, given site conditions, can be used as a design tool for sizing systems; compared with measured output to verify that the system is operating according to design; and, compared with real-time measured output to monitor the functioning of all system components.

Testing PV System Components

To reduce the cost and increase the reliability of PV systems, the PV program sponsors in-house R&D, testing, and cooperative research contracts for non-module components. For example, some of the PVMaT contracts address specific components, such as inverters, controllers, trackers, and batteries. Other contracts seek to improve the entire system through packaged designs.

Steve Durand, Southwest Tech. Dev. Inst./PIX04567

Arizona Public Service installed this PV/hybrid system to power a telecommunications station on Carol Spring Mountain. Thanks to a monitoring system and a good predictive model developed with assistance from Sandia, the utility can follow the operation of the system from headquarters far away.

The national laboratories are important test centers for balance-of-system products. For example, the inverter test facility at Sandia conducts three general kinds of tests. Benchmark testing, when a product comes off the assembly line, characterizes products to enable system designers to properly apply them. Development testing supports manufacturers, PVMaT projects, and efforts in reliability. Acceptance testing verifies that the system or component meets its specifications. Such tests help to spot problems before systems are placed in the field.

Test procedures are evolving to simulate operation in the field. In the laboratory, many types of electrical loads are needed to simulate field conditions—loads that manufacturers would not have. Power supplies including a PV array, a generator, and a large battery bank are available in the laboratory, to support the full range of applications, especially of hybrid inverters.

The testing laboratories of the PV program also support the PV industry with focused product testing. Companies including Trace Engineering, Ascension Technologies, Morningstar, Abacus, Omnion, Outside Power, and Kenetech worked with Sandia researchers this year to test their products. The testing program also assists government agencies, such as the National Park Service and the Navy, and provides technical information at conferences such as Soltech, the IEEE Photovoltaics Specialists Conference, and program reviews.

Testing has been a crucial part of the PV program's R&D efforts, especially in developing new inverters. The Utility PhotoVoltaics Group developed a new high-efficiency inverter that includes maximum powerpoint tracking for control of electrical quality and incorporates a control system for array tracking. PV program engineers also work with companies to improve their off-site testing and quality-control programs.

Batteries are an important component of stand-alone PV systems that can add significantly to the cost of PV-generated electricity. An analysis

performed this year shows that when battery-charging efficiencies and performance lifetime are taken into account, battery costs can be as high as $0.25 to $1.30 per kilowatt-hour over the life of the system. Improving the life expectancy and utilization of batteries, through improved charging algorithms and preventive maintenance, can significantly reduce the cost of electricity from a PV system.

The DOE PV program sponsors battery test and development programs at Sandia and the Florida Solar Energy Center to improve battery performance in PV systems. Batteries can be connected to operating PV systems or can be subjected to accelerated testing through repeated cycling. The program's unique testing facilities and new standardized test procedures allow battery manufacturers to understand the unique demands of a PV system and design products for this growing market.

In addition, the program works to improve charge controllers and charging algorithms, which have a large impact on battery life. To prevent overcharging or undercharging, charge algorithms programmed into controllers use various set points to guide operation. The program has sponsored work to develop and test charging algorithms that can extend battery life

Morningstar Corporation/PIX04580

The SunSaver™ charge controller completed testing this year, confirming that it meets performance and reliability specifications. This improved charge controller should help extend battery life for remote PV applications. Morningstar Corporation, who designed and manufactured the unit under contract to Sandia, has now sold more than 2000 units

Environmental, Safety, and Health Issues

Some of the materials used to manufacture PV cells and modules are toxic, carcinogenic, or otherwise hazardous and must be handled according to strict guidelines. The DOE PV program sponsors research and analysis at Brookhaven National Laboratory and at NREL and Sandia to assess health and safety issues and to develop hazard control strategies for new PV materials, processes, or applications. Research involves three basic approaches to environmental, safety, and health problems associated with PV.

First, researchers develop and promote safe-handling procedures and equipment to keep dangerous materials isolated. This year Brookhaven National Laboratory conducted a toxicology study of precursor compounds used to make thin-film cadmium telluride and copper indium diselenide modules. As a result of this study, safe-handling procedures will be applied to more compounds used by the industry.

Second, researchers work to reduce the toxic waste stream of laboratories and factories through efficient material use and recycling. This year the program completed a detailed study of recycling strategies for cadmium telluride and copper indium diselenide modules. Analysts concluded that all of these metals are recyclable with current technology. They also found that it will be most economic for manufacturers to treat old modules or factory waste to remove constituent metals before transferring the materials to commercial recyclers.

And third, while simplifying processes and reducing the absolute amount of material used in PV cells, researchers sometimes reap benefits from improved environmental safety and health impacts. Reducing the complexity of handling and the amount of materials needed reduces costs. For example, researchers this year achieved good efficiencies on a copper indium gallium diselenide type cell by replacing the cadmium sulfide window with zinc oxide, eliminating an entire layer.

Engineering Systems and Applying PV

Projects that validate PV technology for worldwide markets

Strategic R&D and technology development are the foundation of our efforts to make PV a broadly competitive energy source. But systems engineering and applications are essential to maintaining the connection between technology and real-world markets and uses.

Promoting Projects with Government Agencies

Federal, state, and local governments operate many facilities where PV is a cost-effective way to supply electricity today. To help open this market, the DOE PV program works to get information and technical assistance to staff at all levels of government. This year more projects than ever before were completed in cost-effective installations using PV.

In FY 1996, more than 50 projects totaling nearly 2.5 megawatts of capacity were installed at federal facilities, and another 2.5 megawatts are in the planning stages. The agencies made their decisions primarily by comparing the first-cost of PV to the alternatives. Other issues such as environmental concerns, energy security, and noise levels of engine generators weighed heavily in favor of PV.

Department of Defense

A study conducted by the Department of Defense (DoD) and DOE shows that more than 700 megawatts of PV is cost-effective today for DoD. Each year, the DoD, a big energy user, consumes 300 million gallons of fuel to generate 3000 gigawatt-hours of electricity, for an average cost of between $0.40 and $1.00 per kilowatt-hour. The Defense Department also purchases about 35,000 gigawatt-hours of electricity at a cost of $2 billion per year ($0.06 per kilowatt-hour).

Through Sandia, DOE has supported the Army, Navy, and Air Force since 1985 with technical consultants. In addition, the DOE program has worked with the Coast Guard for hybrid systems, the Marines at Camp Pendleton to reduce energy consumption, the Navy at the Atlantic Underwater Test and Evaluation Center, the First Marine Expeditionary Force Mobile Power Center, and others. The most significant effort, which is now bearing fruit, is integrating PV into the federal procurement system, making it easier for federal agencies to purchase PV systems. The program also assists users in the military that are ready to develop projects by helping them with design and performance issues.

Nearly 2 megawatts of the PV systems under way for the military are stand-alone or hybrid systems. At Superior Valley, CA, the world's largest stand-alone PV system went into operation this year at Edwards Air Force Base. The system includes 350 kilowatts of PV, 3.5 megawatt-hours of battery energy storage, and a 300-kilowatt power-processing unit. Five more hybrid PV systems are being built on remote ranges at the Naval Air Warfare Station. In all, 12 large-scale diesel replacement projects are under way in the DoD that use PV.

Before these large installations could become a reality, the proper power-processing equipment had to be developed. The military, through their Strategic Environmental Research and Development Project, has spent $4.4 million implementing new hybrid power systems. Much of the equipment for these systems has been tested at the PV program's power-processing test facility at Sandia.

Idaho Power Company/PIX01585

This 77-kilowatt PV array is part of a hybrid power system that includes two 160-kilowatt diesel generators and a battery bank. The hybrid system provides high-quality, 3-phase power 24 hours a day for the remote Grasmere bombing range, where sophisticated electronic equipment simulates enemy activities for pilots flying training missions from Mountain Home Air Force Base.

Steve Durand, Southwest Tech. Dev. Inst./PIX04563

Dedicated in August, 1996, this PV/propane hybrid power system replaced generators that consumed 65,000 gallons of diesel fuel per year. In addition, the PV system will help eliminate oil spills and reduce air pollution on Lake Powell.

PV on Public Lands

The U.S. government is the nation's largest landholder. The National Park Service, the U.S. Forest Service, and the Bureau of Land Management all have large recreational areas requiring electric power. For years, the PV program, through Sandia, has been working with these agencies to evaluate their satisfaction with the PV installations they have and to assess the number of additional cost-effective installations they could consider.

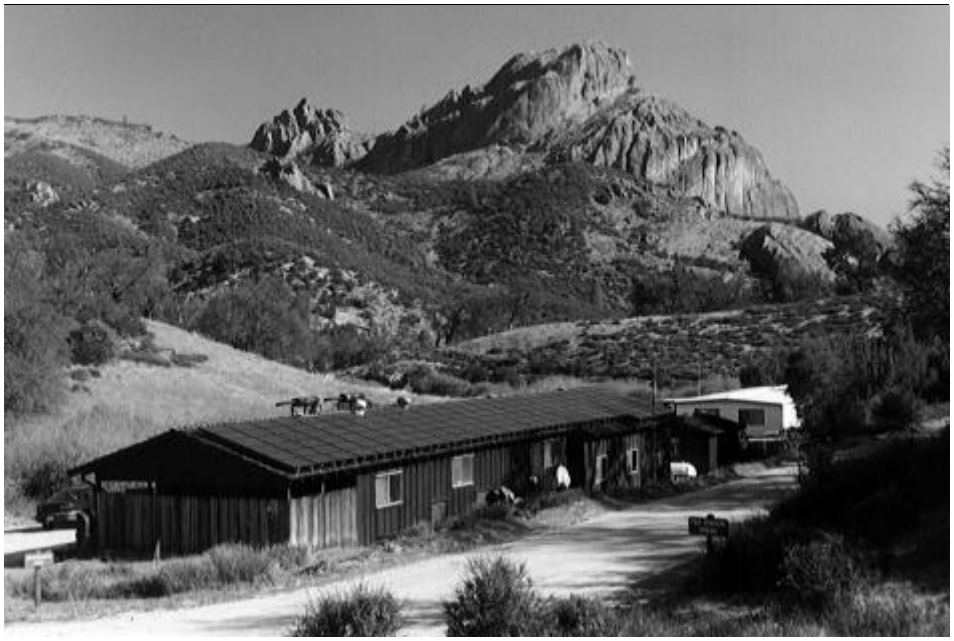
This year heralded the installation of larger PV systems in high-value applications at the National Park Service. The largest, a $1.35 million PV/propane hybrid system, replaced the diesel generator at the marina in Crow Canyon National Recreation Area. The significant environmental benefits from eliminating the diesel system were the major factor in the Park Service's decision to replace existing diesel generators.

The Bureau of Land Management is working with Sandia to specify pilot PV projects in the Western states. The Bureau office in the state of Utah developed standardized specifications for PV systems with help from Sandia. The office is now buying more than 16 standardized systems for recreational use at sites in Arizona, California, Colorado, New Mexico, Oregon, and Utah.

The U.S. Forest Service and Sandia published *Photovoltaic Technology in the U.S. Forest Service—Renew the Forests* this year. This document reports results from surveys of previous PV installations and assesses future cost-effective applications.

State Partnerships

Working at the state level, the Interstate Renewable Energy Council (IREC), supported by DOE and others, launched its training program *Park Power: Using Solar Energy for Public Spaces* (also known as the Workshop in a Box) for state employees to understand options for using renewable energy. The objective of the program is to encourage state and local governments to buy renewable energy products. The first training session, to

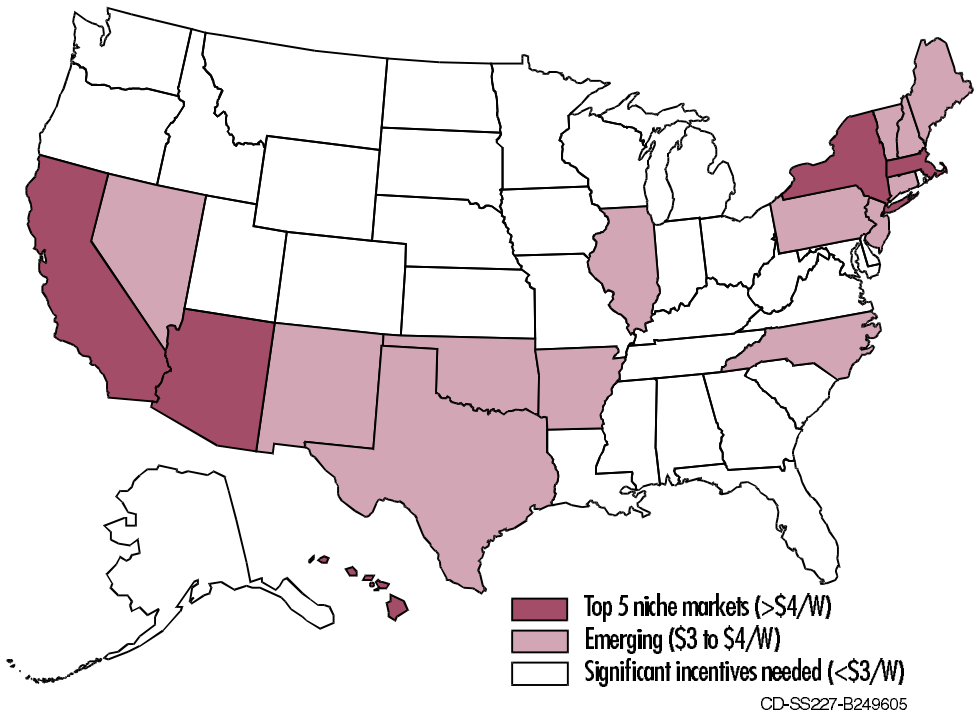


Steve Durand, Southwest Tech. Dev. Inst./PIX04578

Another hybrid PV system installed this year at Pinnacles National Monument supports all the loads in the campground and ranger station facility.

familiarize those who will be using the workshop materials with their use, was held in August 1996. Forty attendees, including 17 state coordinators, and staff from the National Park Service, the U.S. Forest Service, the DOE/Federal Energy Management Program, Sandia, and NREL, learned to use the tools, which include slide presentations, video, and tutorial materials.

Photovoltaics for Utilities, another state-level outreach program supported by DOE, now has state groups working to promote PV projects. A memorandum of understanding was signed to assess state facilities for high-value PV applications and to promote communications among the states. In Arizona, California, Colorado, Delaware, Hawaii, Idaho, Maryland, Massachusetts, Nevada, New York, North Carolina, Pennsylvania, Texas, Virginia, and Wisconsin, state energy offices are teaming with utilities to identify facilities with high energy costs for total operational cost analysis. For example, Virginia identified 100 facilities with energy costs between $0.16 and $30.00 per kilowatt-hour.



A new study identified areas for cost-effective, grid-connected PV applications that reside on residential and commercial customer sites. The two-step analysis looked first at state attributes such as electricity rates and tax incentives, and then performed a cash-flow analysis. In the top five markets, PV could cost more than $4 per watt and still make economic sense for the consumer.

Projects with Utilities

With restructuring, utilities have more reason than ever to explore renewable energy in general and PV in particular. Photovoltaic's modularity, known costs, short construction time, and reliability make PV an attractive way to diversify a utility's generation mix. And the utility market holds great potential for spurring the increased production capacity necessary for reducing the manufacturing costs of PV.

National Solar Enterprise Zone

The National Solar Enterprise Zone is one of many projects under way this year that involves utilities. Located at the DOE's Nevada Test Site, the National Solar Enterprise Zone project goal is to install up to 100 megawatts of renewable power generation capacity in southern Nevada. The nonprofit Corporation for Solar Technology and Renewable Resources (CSTRR) manages the project, reviews proposals from independent power producers that will set up generation facilities in the zone, and will broker the sale of electricity produced.

The DOE PV program supported this activity by having personnel at the national laboratories provide technical support to industry and assist in resolving project issues. CSTRR received preliminary power purchase commitments from the U.S. Environmental Protection Agency and the U.S. Army for a total of 22 megawatts committed by the end of FY 1996.

Utility PhotoVoltaic Group

Some utilities have been interested in PV for many years. In 1992, a group of these utilities formed the Utility PhotoVoltaic Group (UPVG) to speed up the availability of lower-cost, reliable PV systems for themselves and their customers. Among UPVG members, there are more than 80 utilities, the Electric Power Research Institute, the American Public Power Association, the Edison Electric Institute, and the National Rural Electric Cooperative Association. Collectively, the member utilities of UPVG represent more than 40% of total U.S. electricity sales. The activities of UPVG are funded through membership fees and a grant from DOE's PV program. In addition, NREL and Sandia provide technical assistance, such as analyzing power output of inverters, checking basic design and energy production predictions provided by vendors, and reviewing proposals.

This year UPVG's activities solidified utility partnership in PV development; demonstrated applications and markets in PV-friendly pricing, building applications, and off-grid services; and spurred increasing competitiveness in PV products. In 1996, proposals were approved for Round One: 5.6 megawatts of generation for 340 installations. Eleven teams were selected that

each include one or more utilities, as well as PV suppliers and system installers. By far the largest project is the proposal from Amoco/Enron for 3.45 megawatts of grid-connected generation for Hawaiian Electric Company. By the end of FY 1996, about 800 kilowatts of grid-connected PV had been installed for Round One. Round Two also solicited 2.4 megawatts of generation for 1300 proposed installations.

From Laboratory To Marketplace

AstroPower's manufacturing line is currently producing 120 kilowatts of their novel Silicon-Film™ PV modules to be installed at UPVG ventures with utility companies. This commercial success stems from many years of work with the DOE program. AstroPower's silicon cell technology was originally developed with funding and technical assistance from the PV research program. Their module manufacturing processes were improved with funding support from PVMaT. And their early Silicon-Film modules were installed as emerging technology products at PV for Utility-Scale Applications (PVUSA) in Davis, CA, a utility testing ground supported by DOE and others.

AstroPower's more mature technology will now be one of the first large PV arrays installed as part of UPVG ventures with utility companies. PV program support for UPVG continues as the laboratories perform technical assessments, provide module performance measurements for sizing the PV array, and define current and voltage operating windows for the power-conditioning system. AstroPower's modules have been tested outdoors and their performance characterized over a wide range of solar irradiance and operating temperatures using standard reporting conditions.

By working with companies like AstroPower, from the research phase through to production and demonstration, the PV program accelerates the development cycle. The result is more PV product producing electricity today.

Integrating PV into Grid-Connected Buildings

Between the extremes of megawatt-sized fields of PV generators and single panels on thatched huts is a huge potential market for PV integrated right into the structure of modern buildings. A recent market assessment conducted by the Utility Photovoltaic Group identified a potential market of 485-585 megawatts of PV used in buildings for systems priced at $3 per watt.

Building-integrated PV, or BIPV, makes sense for several reasons. First, two-thirds of the electricity generated in the United States is used in buildings. Generating some of this electricity right at the building reduces the cost of transmission and distribution. Second, the considerable space on the roofs and walls of buildings can be used for PV generation capacity. Third, PV products for buildings can replace conventional windows, skylights, walls, and roofing materials, while generating electricity at the same time.

Even though the market looks promising, developing PV products that integrate into the building structure is technically complex and involves segments of the buildings, PV, and utility industries that are normally separate. The need for such unlikely partners to develop a product is a key reason why a government program can accelerate development and use of PV products integrated into buildings. The DOE PV:BONUS (PV Building Opportunities in the United States) project, initiated in FY 1993, sponsored several new products and organized the demonstrations of these products by assembling industrial teams that included architects, building contractors, manufacturers of building materials, utilities, and PV system designers.

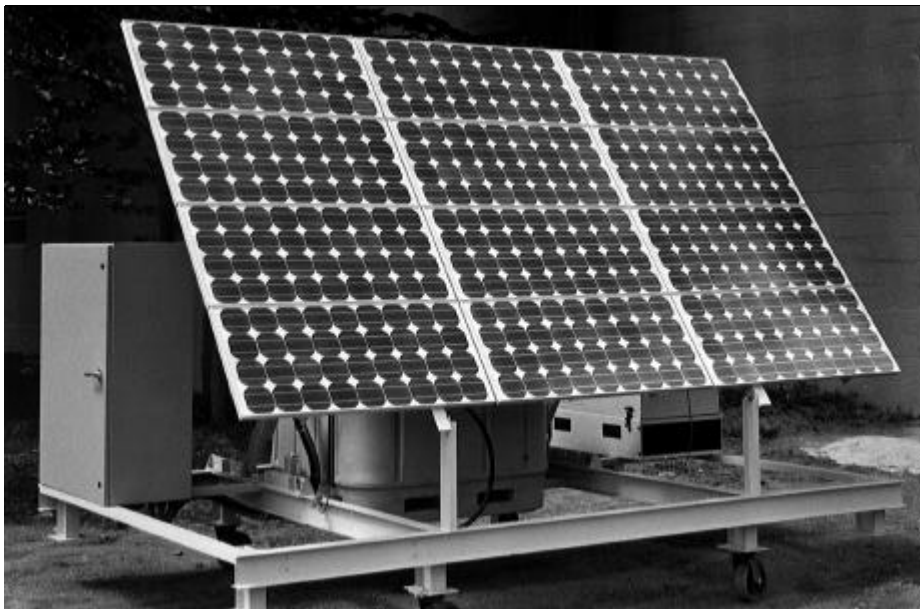
Prime examples of the benefits of this project are the award-winning roofing materials developed and demonstrated by a PV:BONUS team led by Energy Conversion Devices, Inc., Troy, MI. Two new products—a flexible solar shingle and solar electric metal roofing—were developed with support

Rick Hinrichs/PIX04562

The National Rural Electric Cooperative Association sponsors co-ops to test new approaches like this one. One of a dozen prototype systems for pumping water, these panels supplied by Golden Photon, Inc., are made of cadmium telluride thin-film.

from DOE. ECD fabricated prototype products that were tested at NREL and Sandia. This year they installed their improved products on trial applications in conjunction with the National Association of Homebuilders and the Southface Energy & Environmental Resource Center.

Another product developed under PV:BONUS is the ac PowerWall module, which substitutes for plastic or glass in curtain wall or sloped glazing systems in buildings. The modules interface directly with 120-volt ac circuits at the electric distribution panel on each floor of a building and generate up to 250 watts of power per module. They can be manufactured in virtually any dimensions—up to a maximum of 53 inches by 87 inches—to meet building design specifications. The team that developed this product included Solar Design Associates, an architectural and engineering firm; Solarex, a PV module manufacturer; and ASE Americas, Inc, a PV module manufacturer.



PV Services Network/PIX04576

PV Services Network (PSN), incorporated in 1994, came into its own this year. Their 54 member utilities have purchased and installed more than 300 systems, mostly in the western United States. Before the PV Services Network, each utility had to design its own systems in house. Through a bid process, PSN encouraged suppliers to design and offer package systems for a specific price and delivery schedule. PSN also requires suppliers to issue a 2-year warranty on their products. They select suppliers based on the predicted performance of their systems, reliability of their company, and price.

John Haigwood/PIX04577

The PV shingle shown here deployed on a house in Atlanta, Georgia, won Popular Science Magazine's grand award for What's New in Environmental Technology. The PV shingles cover the inner portion of the lower roof section.

Documenting Performance for International Applications

The potential demand for a reliable source of electricity in the developing world is staggering and resulted in the export of about 75% of our domestic production of PV in 1996. More than 2 billion people, or 40% of the world's population, lack a reliable source of electricity. As our production capacity grows to meet this demand, PV will become a larger component of our export economy.

For PV products to reach this market, however, structures for financing, installing, and maintaining systems must be developed within each country. Although international lending agencies are interested in renewable energy technologies, performance must be documented before loans are granted. And organizations within countries must be familiar with the technology and its requirements to successfully incorporate it into their energy planning.

Robert Foster, Southwest Tech. Dev. Inst./PIX04564

This PV pumping system, installed as part of DOE's efforts in Mexico, supplies the domestic water for a community of 31 families in a rural area of the state of Chihuahua.

The PV program carries out country-specific pilot projects in partnership with national or state institutions to document the performance of PV technology and U.S. industry. This year, projects in Brazil, India, China, and Mexico demonstrated the benefits of PV and PV/hybrid installations.

China—In 1995, the Secretary of Energy signed a protocol agreement with the State Science and Technology Commission of China. This protocol established the framework for Sino/American cooperation to develop renewable energy technologies and markets in China. NREL is conducting a series of case studies in Mongolia for household and village-power systems to develop technical and economic performance data. The NREL team published a report with the University of Delaware, *Levelized Cost Analyses of Small-Scale, Off-Grid Photovoltaic, Wind, and PV/Wind Hybrid Systems for Inner Mongolia, China*. The report concludes that from both a systems and users perspective, stand-alone renewable-energy home systems generate energy for less cost than diesel generators. Therefore, a large market for household-scale renewable-energy systems should exist in Inner Mongolia.

Brazil—Prompted by the Earth Summit in Rio de Janeiro in 1992, DOE, together with the state-owned electric utilities of Brazil, has organized the installation of more than 800 PV lighting systems from U.S. manufacturers. This year, two 50-kilowatt village-scale hybrid power systems went into operation to replace diesel generators. The two systems represent significantly different approaches to the problem of remote power supply using renewable energy. Deployment and assessment of the systems will give the Brazilian utilities experience and information about hybrid power for use in future projects. Data from these projects will then be available to the World Bank and others to support requests for financing additional projects.

India—As a direct result of a DOE trade visit to India in February 1995, Solar Cells, Inc., of Toledo, OH, signed up an India business partner to introduce and distribute SCI solar power modules into the growing Indian PV market. Applied Power Corporation of Lacy, WA, will supply 30 kilowatts of PV modules, charge controllers, and a surface water pump for the Ramakrishna Mission project in West Bengal, India. Remote Power Associates of Ft. Collins, CO, will train people in India to install and maintain the systems. In all, 300 homes in seven villages will have electric lights, auxiliary power sockets, and street lights for the first time. The project cost will be equally shared between DOE and agencies within India.

Mexico—DOE and the U.S. Agency for International Development (USAID) are co-sponsoring a program to incorporate renewable energy technologies into established Mexican programs (totalling $245 million) aimed at increasing productivity in the countryside. The program is managed by Sandia, with NREL providing technical assistance through its wind program. Through training workshops and pilot projects sponsored by DOE and USAID, several Mexican rural development organizations are gaining the technical and institutional experience to incorporate PV into their ongoing programs.

Programs to promote pumping water with PV in Mexico are especially promising. Rural demand for water in Mexico represents a potential market of more than $2 billion for PV. To demonstrate the performance of PV for rural water pumping, the PV program has helped to initiate 36 PV water-pumping projects in the Mexican states of Chihuahua, Sonora, Baja California Sur, and Quintana Roo. More than 60 additional projects are planned for 1997. Most of these water-pumping projects are planned in partnership with the Mexican Trust for Shared Risk (FIRCO). As a result of these successful projects, Sandia will help FIRCO extend the program throughout Mexico. Work has already begun to duplicate the successful projects in five additional states.

Many Mexican states have large ecological reserves with demands for electric power. The PV program is working with the Nature Conservancy, Conservation International, and the World Wildlife Fund to install PV as a clean, quiet source for the electricity needed to manage the reserves. This year six installations were completed in projects funded jointly by DOE, USAID, and the conservation organizations.

These efforts help ensure that renewable technologies and American business will benefit from World Bank and Global Environment Facility funds. Sandia is keeping the U.S. renewable energy industry involved in the program through facilitating partnerships between U.S. and Mexican vendors, and through commercialization assistance with new technologies.

In addition, several activities generally promote export of PV. These projects, which cost relatively little, have the potential to greatly impact our domestic PV industry. For example, international standards-making bodies need input from the United States. DOE PV program personnel support Task V of the International Energy Agency's Implementing Agreement for a Cooperative "Grid Interconnection of Building Integrated and Other Dispersed Photovoltaic Power Systems." The task will develop technical guidelines for low-cost, safe connection to electric grids throughout the world. The United States will lead a subtask on non-technical barriers, which will evaluate economics and market potential, assess barriers to realizing that potential, and develop strategies for overcoming institutional barriers.

Engineering Certifiable Products

Utilities, building owners, and other potential purchasers of PV products look for assurance that these products will perform as advertised. The DOE PV program has worked with industry and various standards-making groups for years to develop standard ways of reporting and verifying PV module and system performance.

This year a certification program for modules sold in the United States came several steps closer to realization. Arizona State University, with DOE support, developed a guide for accrediting laboratories to set up a national PV module certification program. Their final report, *Photovoltaic Module Certification/Laboratory Accreditation Criteria Development: Implementation Handbook*, was used to establish PowerMark Corporation, which will use third-party testing performed by accredited laboratories to certify PV modules in the United States. Four U.S. module manufacturers actively support this effort because they view it as helpful in establishing buyer confidence in their products.

In addition, an Institute of Electrical and Electronics Engineers (IEEE) standards coordinating committee approved the first consensus standard of qualification practices for flat-plate PV modules. The tests specified in the document, many of which were developed and validated at DOE laboratories, cover crystalline-silicon and amorphous-silicon flat-plate modules and can be used for other thin-film modules.

Another useful tool for consumers will be a module energy-rating method being developed by the PV program. The methodology describes how to measure module characteristics under certain sets of weather and load conditions. When validated with data from actual systems operating in the field, the method will estimate module performance under specified conditions using a combination of models.

In other standards activities, the PV program supports efforts through IEEE to develop a standard for utility interconnection of PV systems. In addition, DOE supports the Solar Energy Industries Association to provide PV industry representation and feedback for changes to the National Electrical Code. Almost 50 PV-related proposals have been submitted for the 1999 cycle of the National Electrical Code.

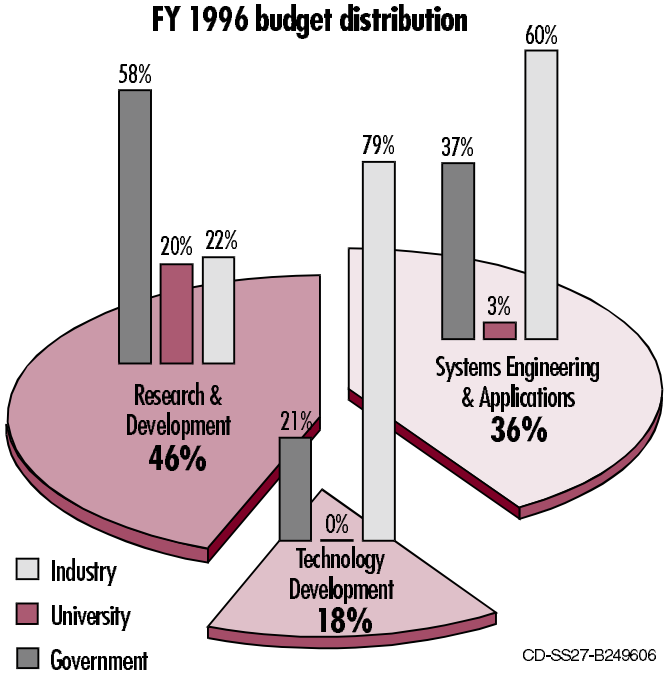
Managing Program Resources

A National Center uses resources efficiently

The National Center for Photovoltaics

The National Center for Photovoltaics (NCPV) was created this year to strengthen communication and further unify national PV interests. The large number of participants—the PV industry, associations, consortia, utilities, and other end-users—involved in developing this technology grows each year. As we enter the present era in photovoltaics, the direct personal interaction once used to apply resources to problems must be augmented.

The NCPV will serve as a focal point for all the nation's capabilities in photovoltaic research, development, deployment, and outreach. The National Center unites geographically dispersed researchers in a common purpose, with the sum greater than the individual pieces. Based at DOE's National Renewable Energy Laboratory, the NCPV draws on the core expertise of NREL and Sandia National Laboratories to guide operations and coordinate support from other resources. These other national PV resources include Brookhaven National Laboratory and DOE's Centers of Excellence in PV at the Georgia Institute of Technology and the Institute of Energy Conversion at the University of Delaware. In addition, dozens of university and industry research partners across the country are linked together to function in a more unified way. And the NCPV's use of electronic communications and interlinked databases ensures all members of the PV community fast, easy access to the growing body of knowledge about photovoltaic systems and their applications.



Facilities Available

Because most companies cannot afford large research facilities of their own, the National Photovoltaics Program conducts long-term, high-risk, high-payoff research, development, and testing of photovoltaic components and systems in partnership with the PV industry. The world-class facilities of the national laboratories make this possible.

Material and Device Development—Competencies include solid-state spectroscopic analysis, experimentation with photoelectrochemical processes, and the application of advanced theoretical and computational tools for predicting the behavior of new PV materials.

Module and System Development—Facilities include laboratories for fabricating and evaluating thin-film technologies (amorphous silicon, cadmium telluride, and copper indium gallium diselenide), crystalline-silicon cells and modules, concentrator cells and PV arrays, and for developing and testing balance-of-systems components such as charge controllers and inverters.

Measurement and Characterization—Competencies include analytical microscopy, electro-optical characterization, surface and interface analysis of materials, analysis of cell and device operation, computer modeling of system and component performance, and the development of special measurement techniques and instruments for U.S. firms.

Performance and Reliability Testing—PV technologies are tested using outdoor test beds, indoor laboratories, and field trials. Equipment can be tested under simulated and actual outdoor conditions, and under varying temperature, humidity, precipitation, and radiation levels.

Manufacturing and Deployment—Cost-shared development programs evaluate and resolve technical issues in the production of PV components and systems. DOE experts of the National Center work with large user groups such as utilities to address technical issues in deploying PV technologies in new applications.

Market Development and Outreach—Information and outreach activities of the staff include assisting those who buy systems, finding ways to finance PV installations, and analyzing technological, economic, and environmental impacts for specific applications.

Solar Resource Characterization—State-of-the-art measurement systems traceable to world standards are used to characterize solar resources. Electronic data sets, maps, and models are available to quantify or estimate the distribution of solar radiation for specific locations.

Together with their research partners in industry and universities, the national laboratories comprise the National Center for Photovoltaics, a formidable resource for the U.S. photovoltaics industry to remain ahead in the global market for photovoltaic technology.

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